Simulation and Analysis of Real Foam Microstructures

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Cellular solids are ubiquitous in nature (e.g., wood, bone), and have been found increasingly valuable in meeting the material demands of an expanding suite of specialized engineering applications (e.g., honeycombs, foams). These materials have unique characteristics relative to more common structural materials, including complex, irregular structure at the cellular scale, i.e., the microstructure. Recent research on polymeric foams is advancing modeling, simulation, and analysis capabilities applicable to Laboratory system components in particular, and cellular solids more generally.

Polymeric foams are light-weight structural components with unique mechanical properties and applications. They are used in packaging to isolate components and absorb energy. They routinely operate over a large range of compressions in service. Well-established "rules of thumb" exist for estimating foam bulk mechanical response from parent material properties and a few basic characteristics of the cellular microstructure. However, the range of mechanical response measured for nominally identical foams clearly indicates that additional characteristics are important.

While this would seem to be a promising scenario for contributions via computation, the simulation of foams is a well-established computational challenge for several reasons: 1) The deformations of interest are large, both bulk and on the cellular scale, 2) extensive "self contact" must be simulated as the microstructure collapses upon itself, and 3) realistic foam microstructures are irregular and difficult to discretize for computations using a body-fit mesh. This combination of challenges has limited many modeling efforts to small deformations and idealized foam microstructures.

Recent developments in particle-in-cell (PIC) methods indicate that these numerical techniques are suitable for precisely this class of problem. Using experimentally determined foam structures (Fig. 1), quasi-static compression was simulated with results in agreement with experimental data in the literature. It was predicted that the full foam sample is an auxetic material at modest compressions, and that it becomes progressively more difficult to remove porosity, resulting in residual porosity even in "fully densified" foam [1].

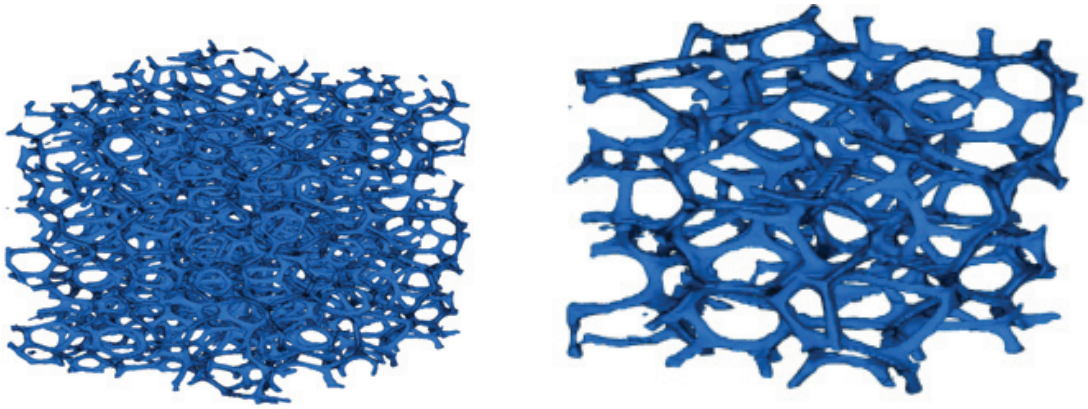

Fig. 1.
Full sample of a foam microstructure (3.4 x 3.4 x 2.7 mm^3) and an 1/8 sample obtained from the bottom right corner.

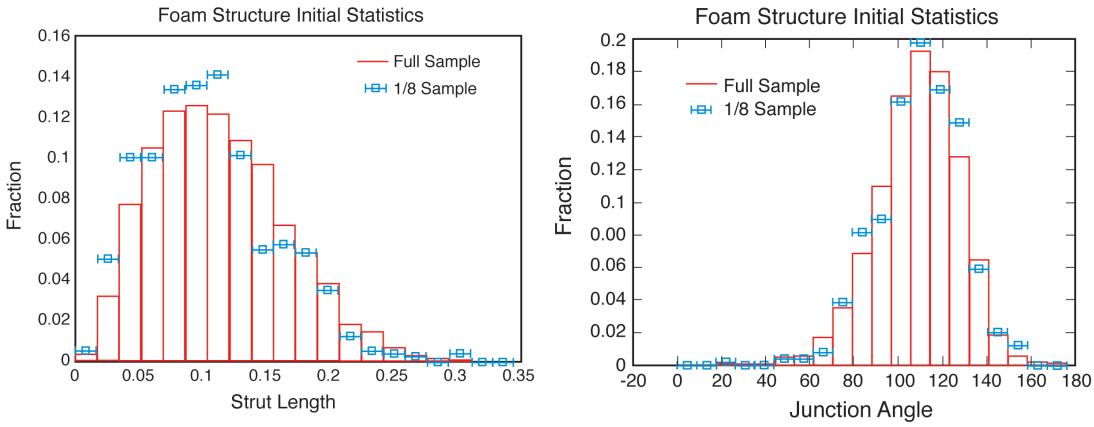

Fig. 2.
Strut length (left) and strut junction angle distributions.

More recently, image analysis has been used to identify microstructural features. Figure 2 highlights the differences in strut lengths and strut junction angles (determined pair-wise) between the full foam sample and the subsection, both depicted in Fig. 1. Variations in both microstructural features and average compressive response are being compared in order to 1) characterize foam deformation in detail and identify the features which affect bulk response, and 2) determine the quantity of material required to produce mechanical response representative of bulk foam.

Experimental techniques are being used to measure deformed foam microstructures, providing detailed validation data. An approach to developing bulk foam constitutive models is under development in which bulk response is obtained from unit cell mechanics models, foam structure statistics, and variations in average response. The simulations and analysis described here will be used to calibrate this theory, connecting material scales and providing an additional validation path.

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[1] A.D. Brydon, et al., *J. Mech. Phys. Solids* **53** (12), 2638–2660 (2005).